

Urea SCR and DPF System for Diesel Sport Utility Vehicle Meeting Tier 2 Bin 5

DOE and Ford Motor Company Advanced CIDI Emission Control
System Development Program
(DE-FC26-01NT41103)

Diesel Engine Emission Reduction Conference

Christine Lambert

August 25, 2005



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Presentation Overview

- Program Overview
- Results with Fresh Catalysts
- System Durability
- Improved Oxidation & NOx Catalyst Development
- Exhaust Gas Sensor Development
- Urea Infrastructure Study
- Conclusions

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Program Overview



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DOE Ultra-Clean Fuels Program

Outline of Ford's program to achieve Tier 2 FTP emission standards for 2007 using low sulfur diesel fuel as an enabler for a high efficiency aftertreatment system.

Primary Contractor



Subcontractors



Catalyst Suppliers



Johnson Matthey



Phase I - Initial build/test phase (July 01-July 02)

Establish baseline emission control system

Deliver engine dynamometer NOx and PM test results

Deliver prototype vehicle NOx and PM test results

Deliver urea delivery (infrastructure) prototype

Phase II - System/component optimization phase (July 02-July 04)

Define final system hardware components

Deliver NOx and PM performance data from fresh system

Phase III - Durability phase (July 04-Dec 05)

Definition of durability test procedure

Final NOx and PM emission levels

Final report for the completed program

FEV Program

Engine Dynamometer

- Urea SCR/CDPF optimization
- Transient FTP testing

Emission Control System Durability

- 120K miles on engine dyno

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Urea Infrastructure

- Co-fueling concept
- Cold-climate urea usage
- Infrastructure studies

Fuel Development

- Make and use fuel, which will be typical of 2007 production with 15 ppm sulfur cap



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Diesel Fuel Properties

- ExxonMobil blended 14,000 gallon batch to represent typical 2007 ULSD

Fuel Property	Est. Avg. '06 Diesel Properties	Proposed DOE Program Min/Max	Program Fuel Delivered	Proposed 2007 Cert. Fuel
Sulfur, ppm	15*	10 / 15	12.5	7 / 15
Density, kg/m³	850	820 / 850	841.1	839 / 865
Aromatics, vol. %	32	25 / 32	29.5	27 min
Polyaromatics, wt. %	10	6 / 11	11.0	no spec
Cetane number	46	44 / 48	44.9	40 / 50
T50, C	267	250 / 280	249	243 / 282
T90, C	306	300 / 320	307	293 / 332

* As delivered to the vehicle



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Results with Fresh Catalysts



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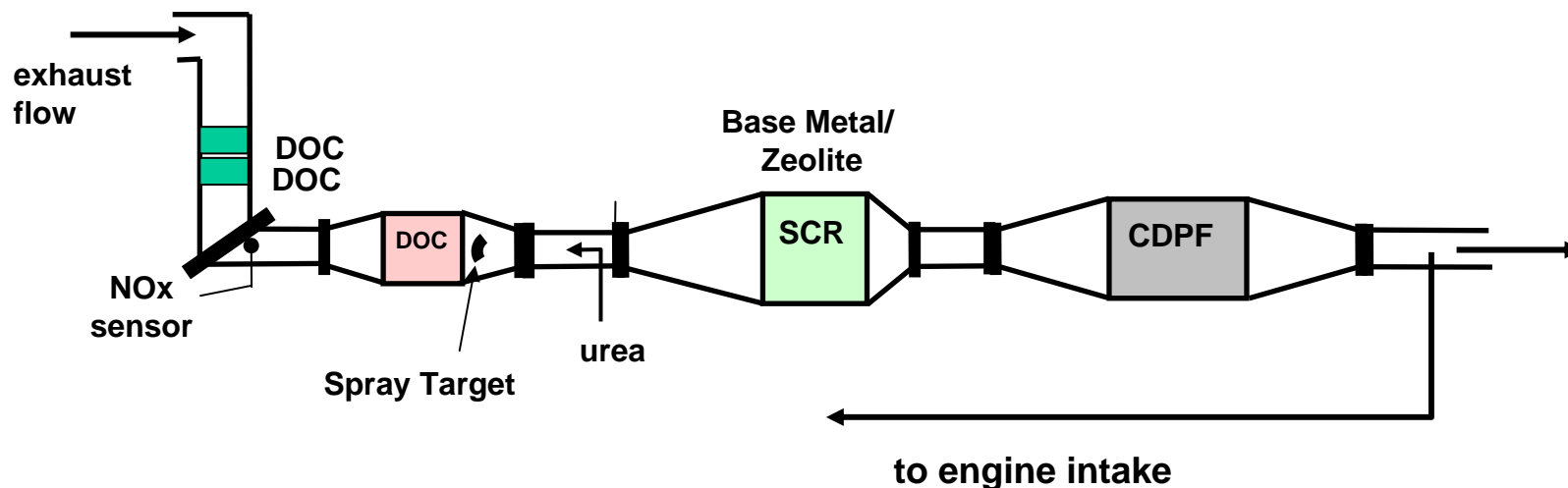


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Exhaust System for 6000 lb Prototype LDT

Targets: 0.07 g/mi NO_x, 0.01 g/mi PM



- Engine-out NO_x lowered by 40% with increased EGR*
- Low tailpipe NO_x achieved with rapid warm-up strategy
 - lower thermal mass upstream of catalyst system
 - engine calibration changes during cold start (post injection & inc. idle speed)

* Tradeoffs for lower engine-out NO_x include lower fuel economy & higher PM.



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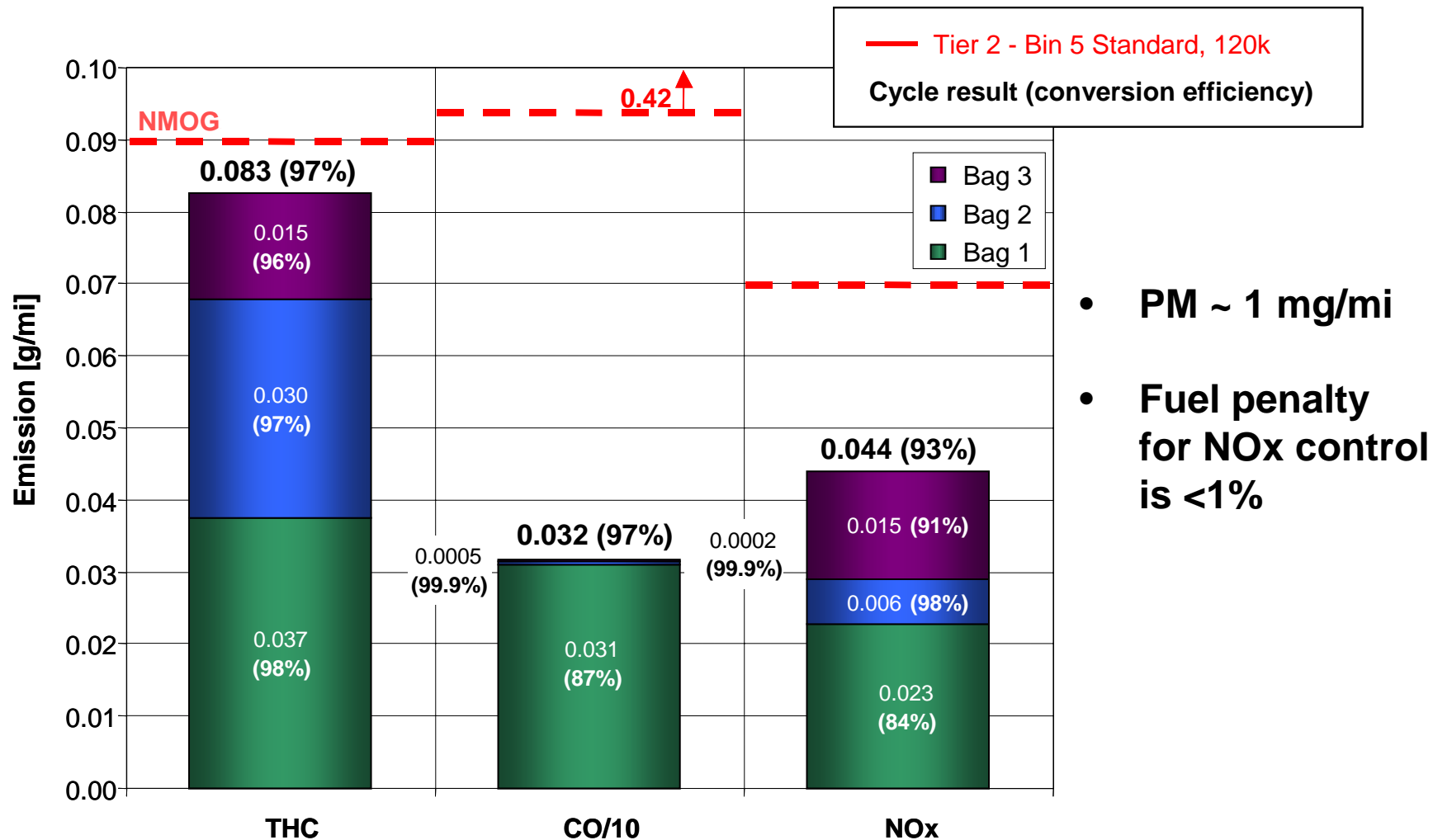
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FTP-75 Tailpipe Emissions and Conversions

Fresh catalysts on Engine Dyno



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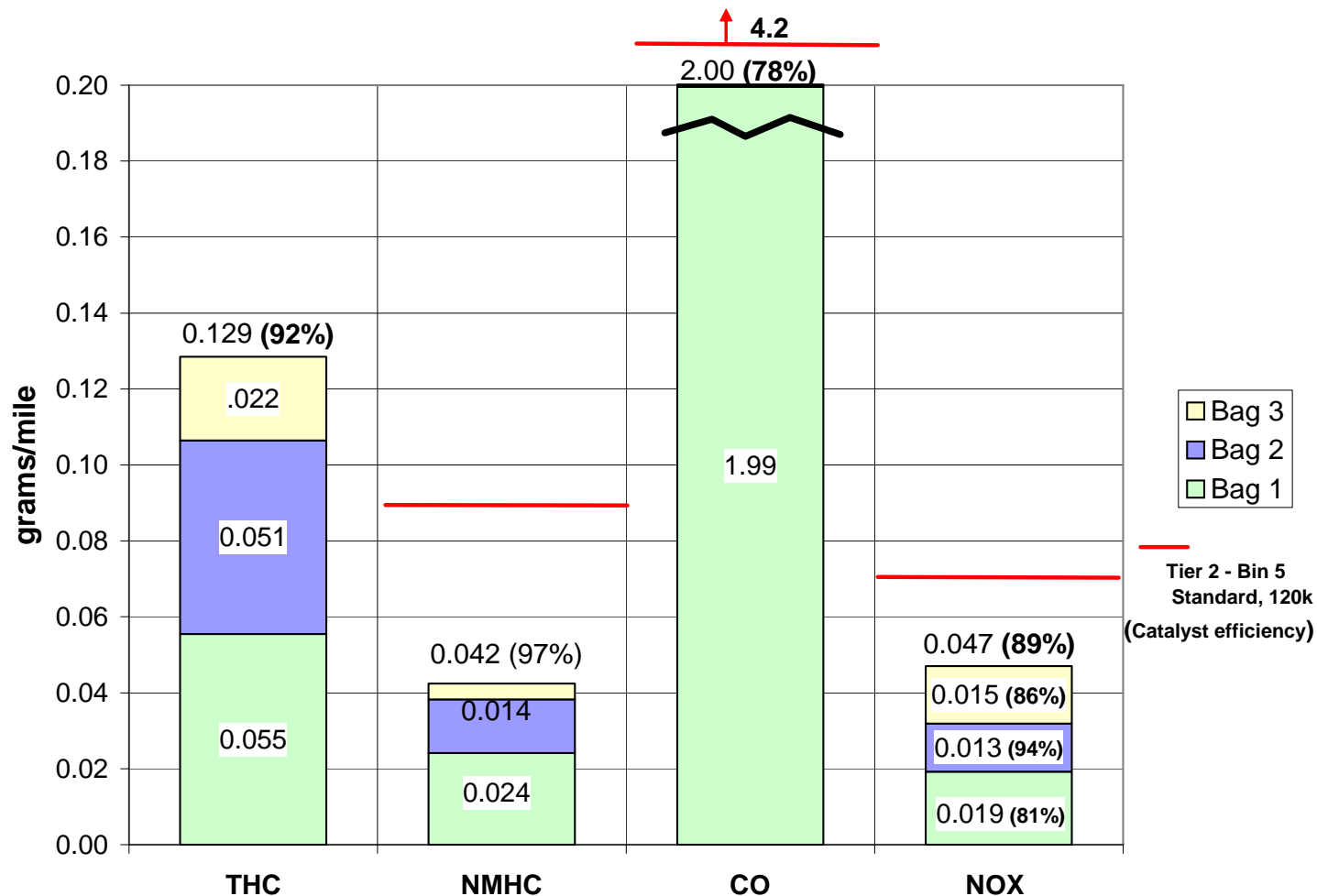
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Vehicle Testing

6000 lb LDT FTP Emissions, Low-mileage



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System Durability



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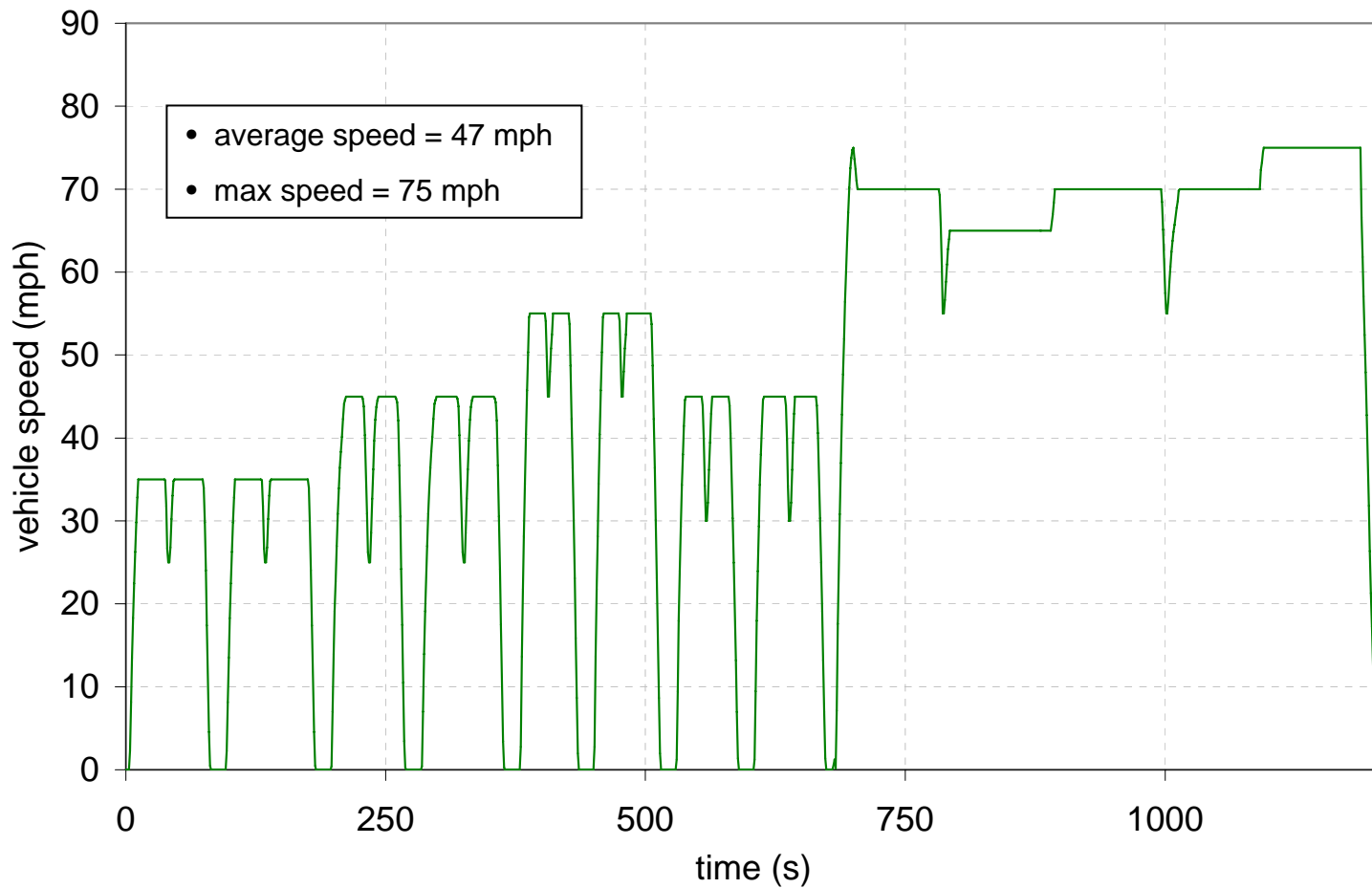


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Durability Test Definition

Ford High Speed Cycle (HSC)



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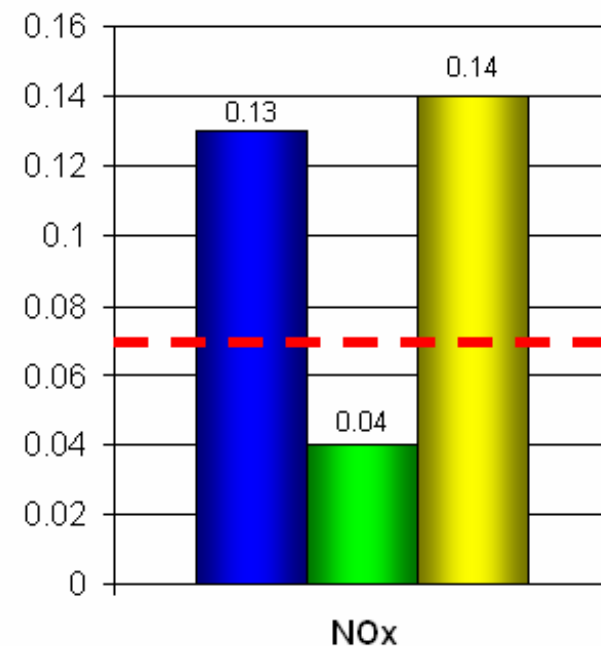
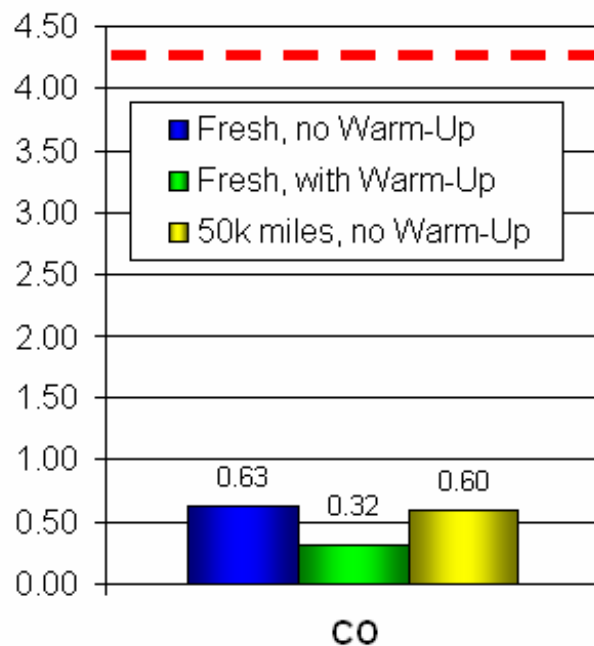
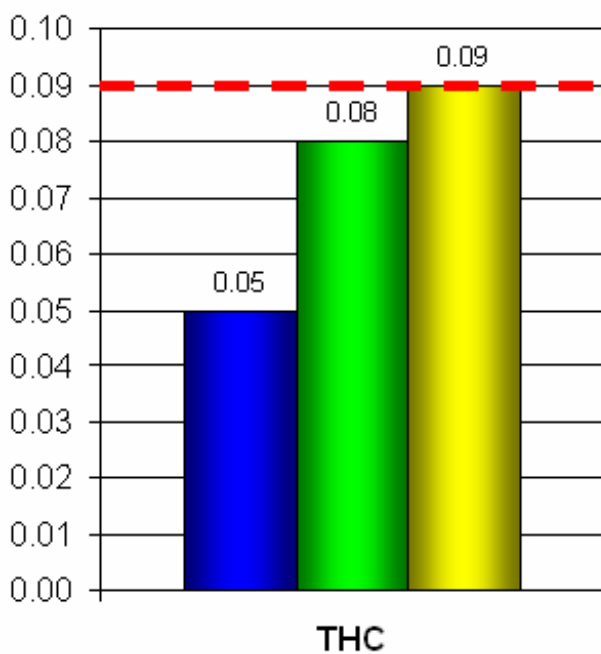
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Engine Dynamometer Durability Testing 50K Mile Performance Evaluation

Tailpipe Emission Levels Over Simulated FTP-75 Vehicle Cycle Urea SCR and CDPF Emission Control System

--- Tier 2 – Bin 5 Standard, 120k



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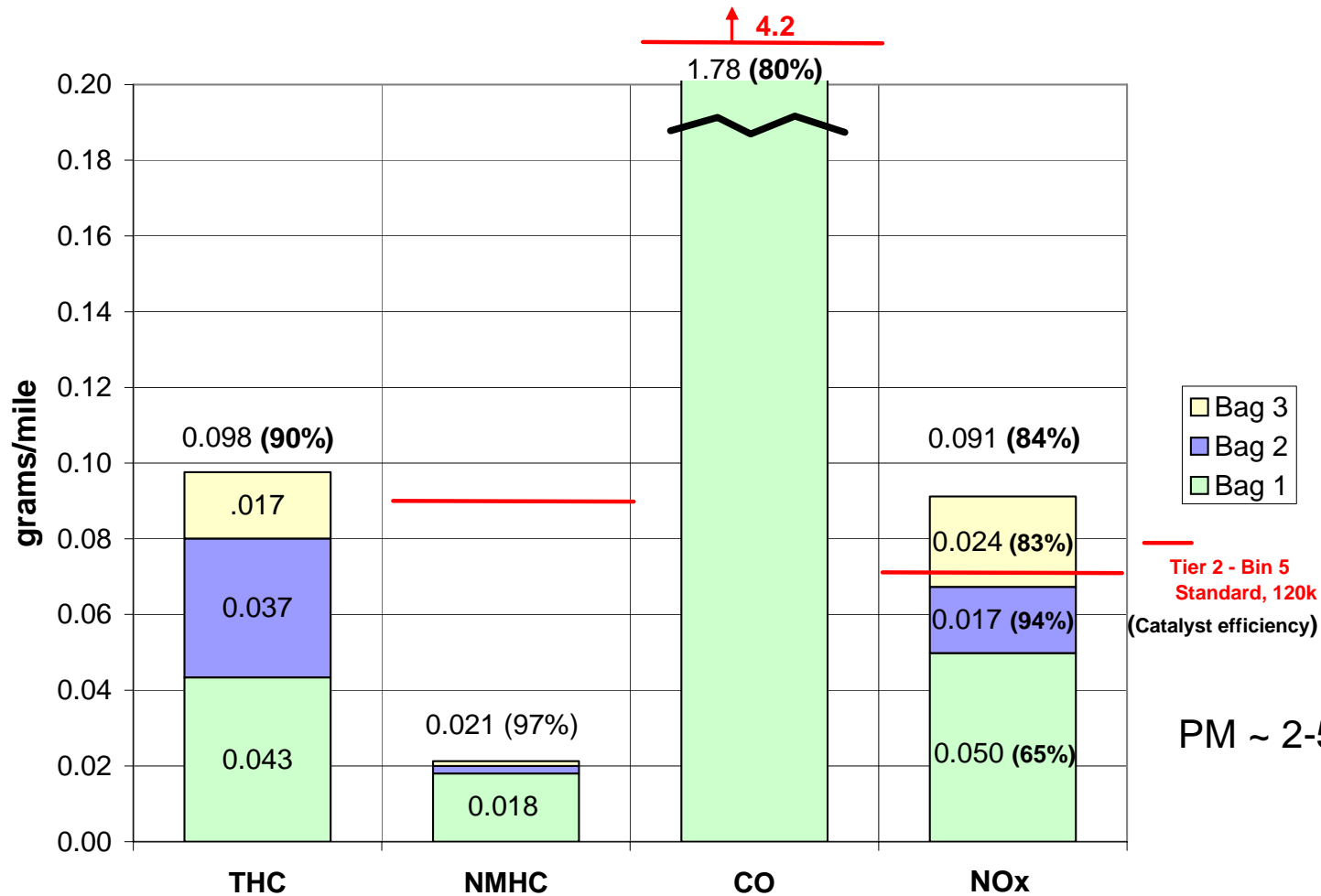
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Vehicle Testing of 50K mi Catalysts

6000 lb LDT FTP-75 Emissions

NO RAPID WARM-UP



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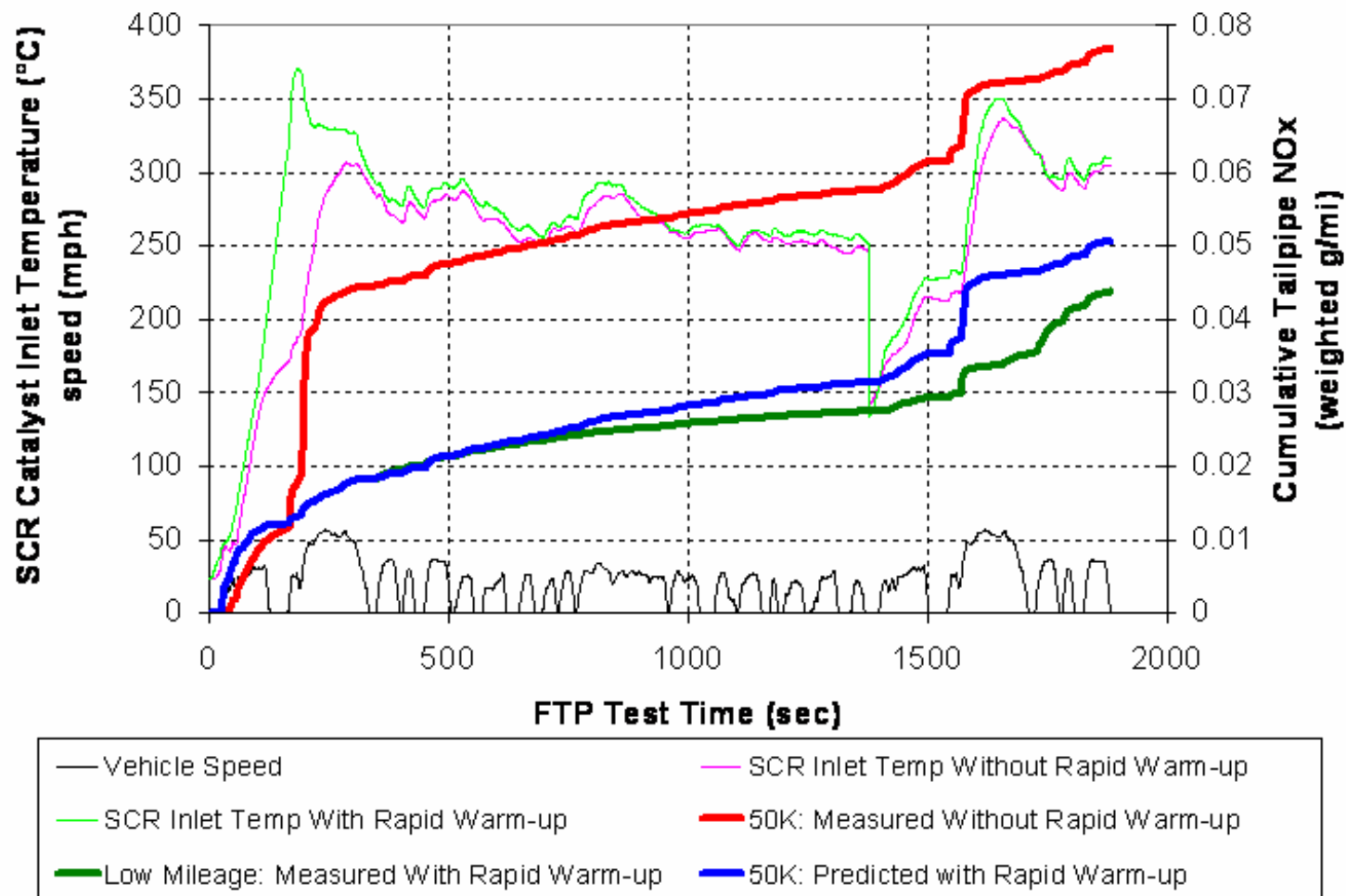
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Vehicle Testing

Predicted NOx Emissions with 50K mi Catalysts and Rapid Warm-up on 6000 lb LDT



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Improved Oxidation & NOx Catalyst Development



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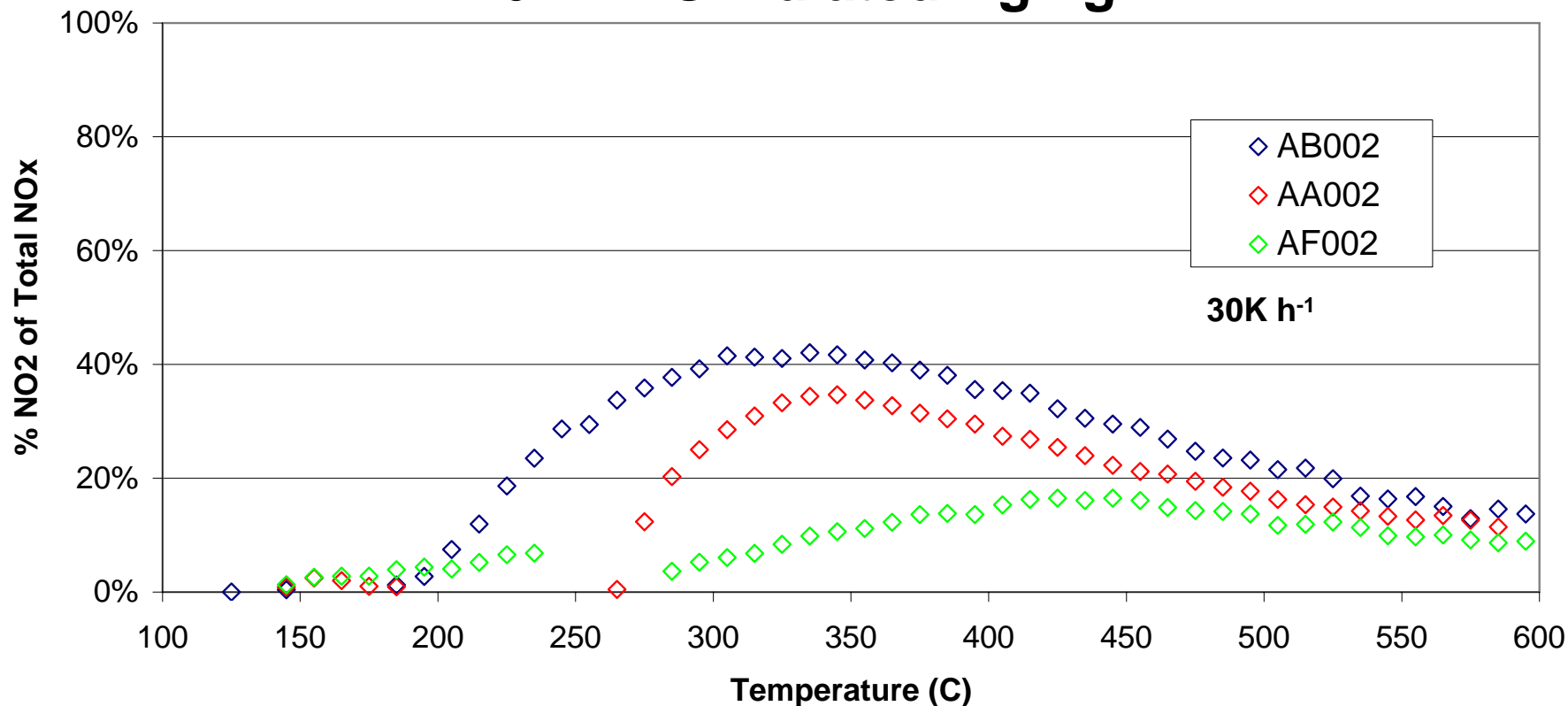
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Oxidation Catalyst Evaluation

$\text{NO} \rightarrow \text{NO}_2$ Conversion

120K mi Simulated Aging



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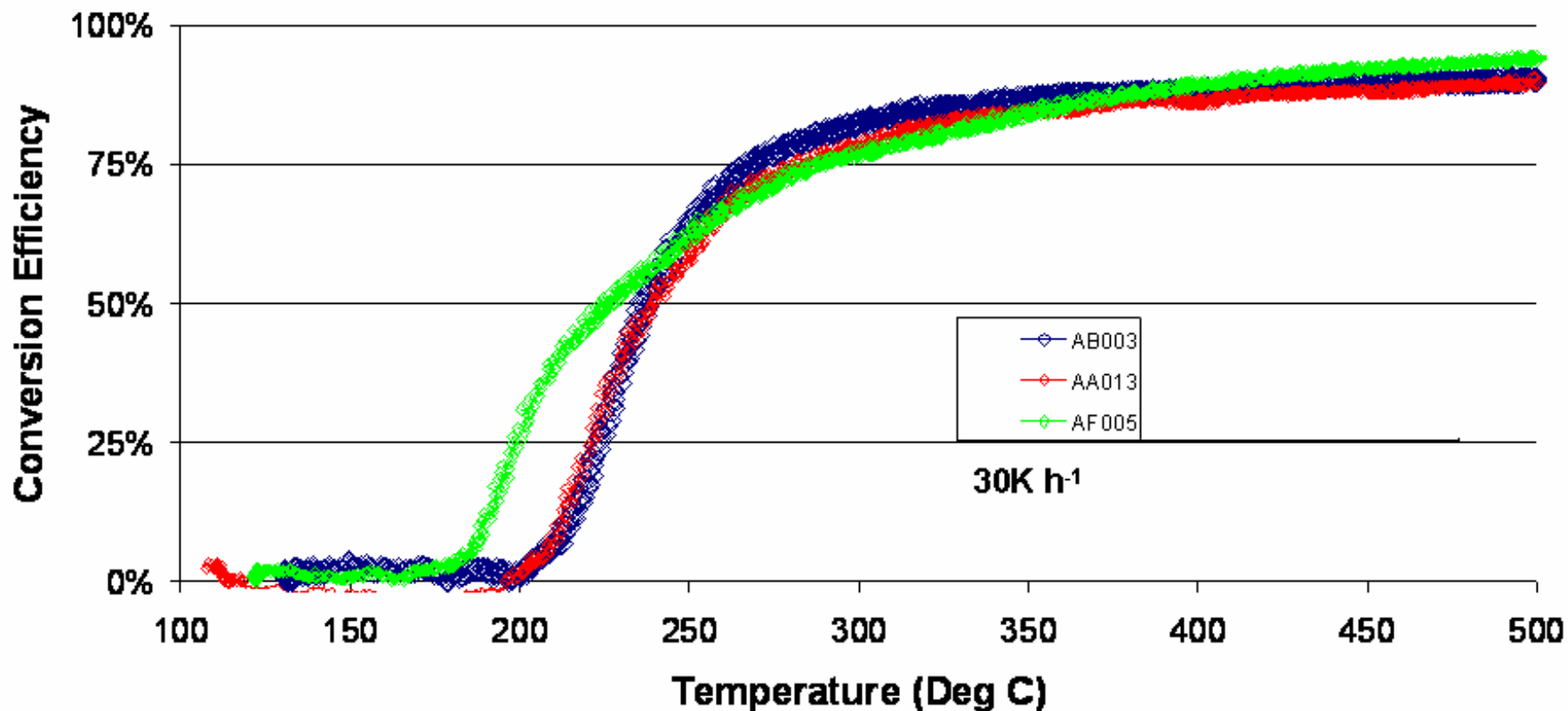
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Improved Oxidation Catalyst Evaluation

HC Conversion

120K mi Simulated Aging



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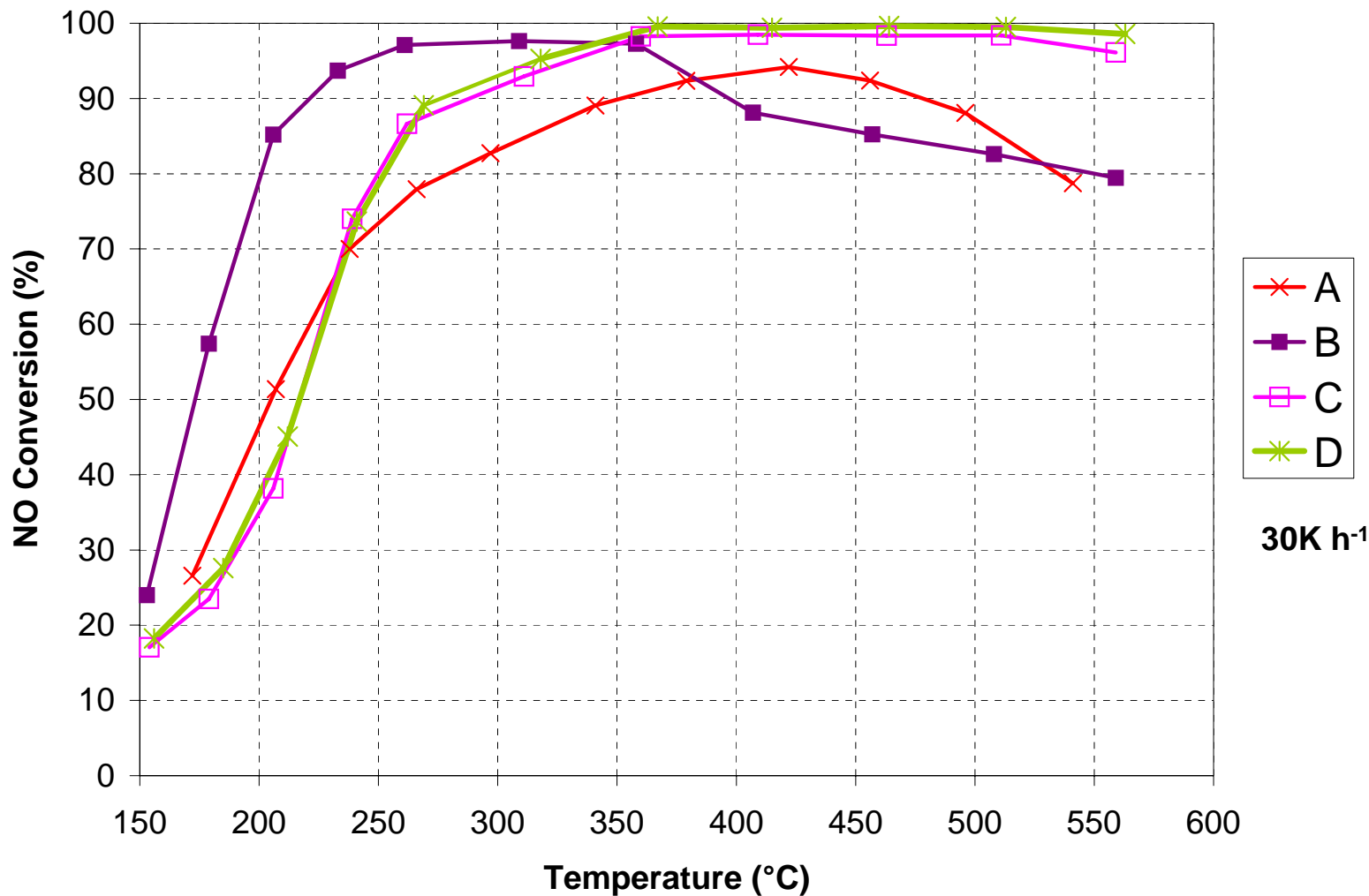
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Comparison of Improved SCR Catalysts

Aged 64 hrs at 670°C, Evaluated with NO only



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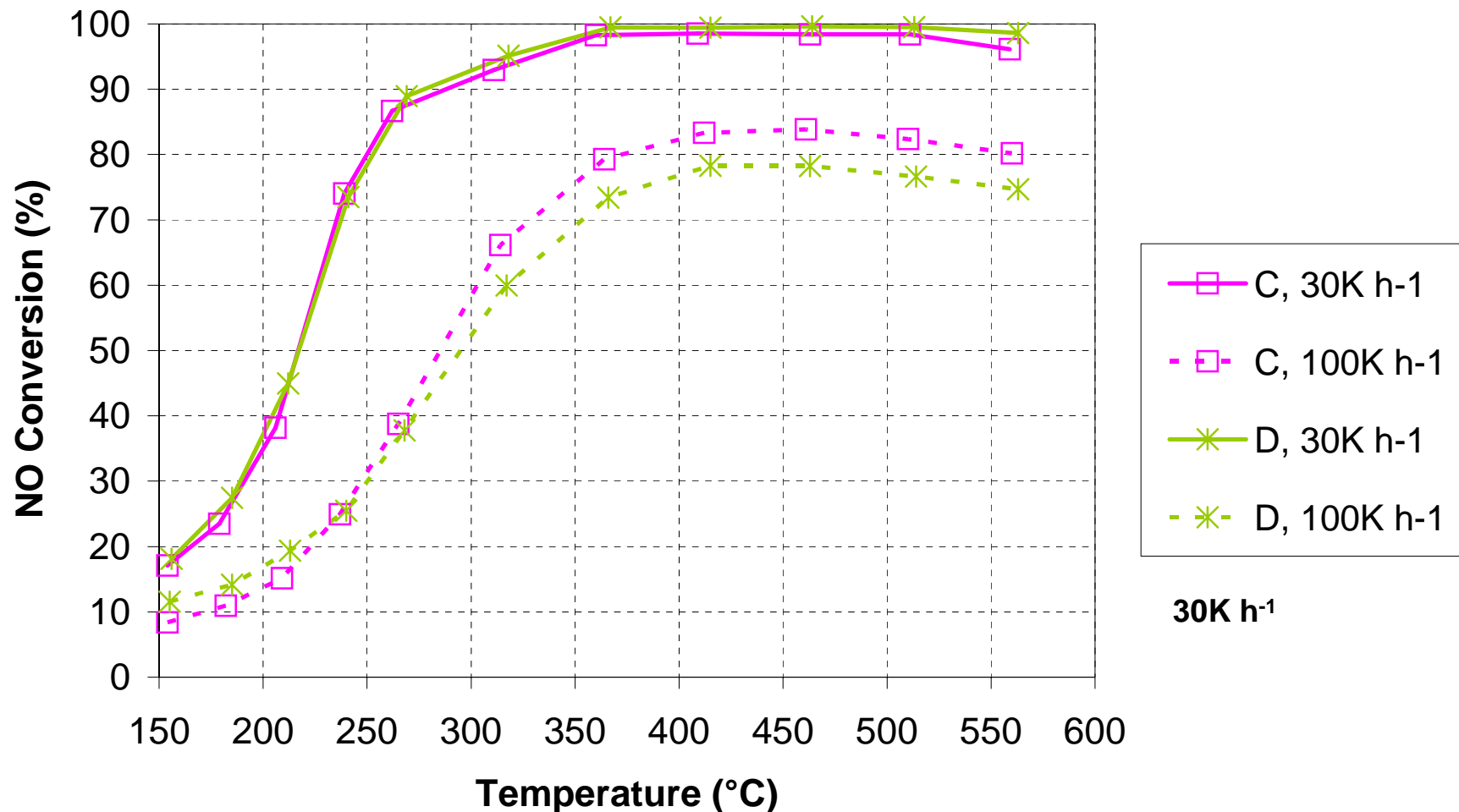
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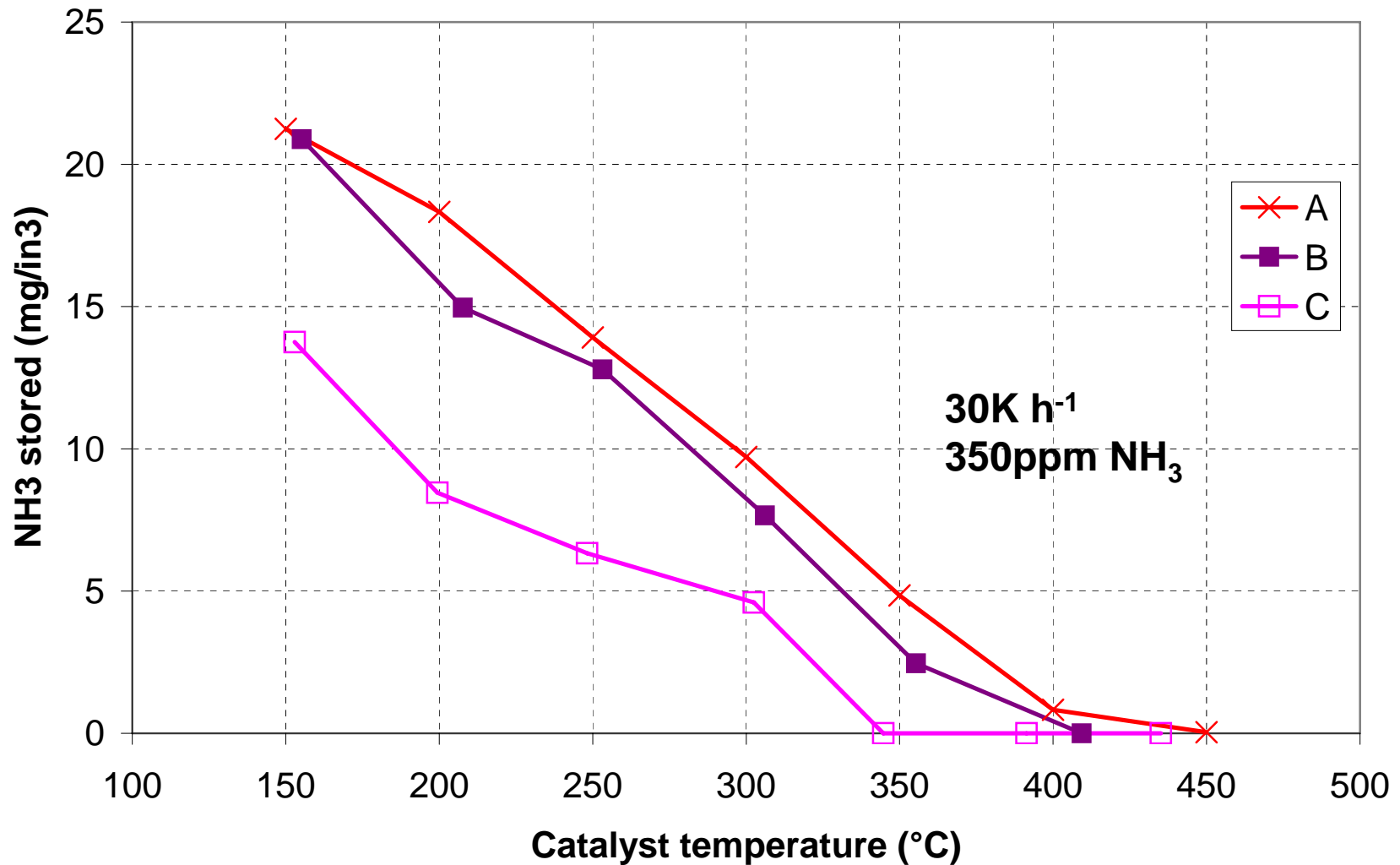
Comparison of Improved SCR Catalysts

Aged 64 hrs at 670°C, Evaluated with NO only



Comparison of Improved SCR Catalysts

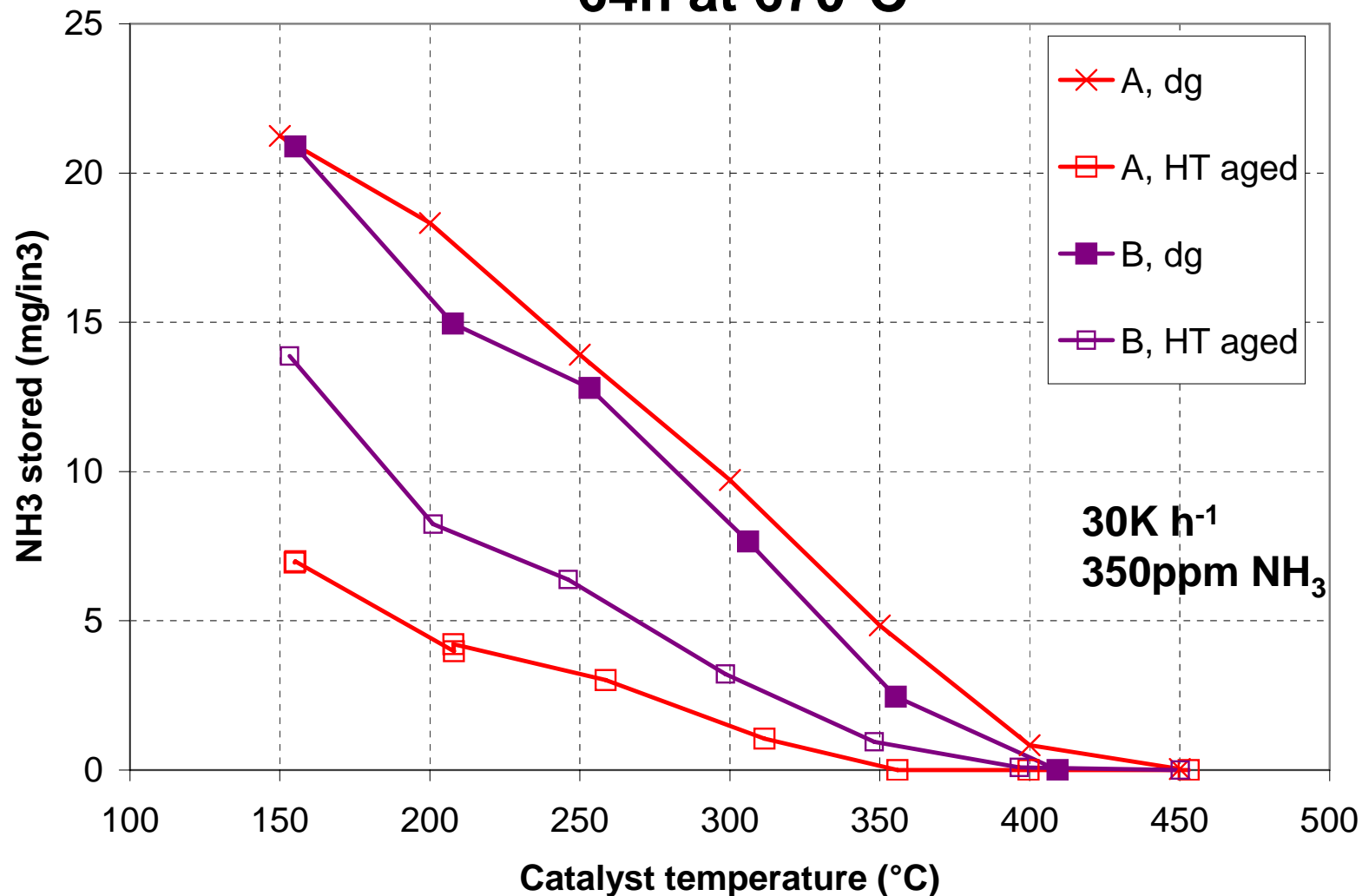
Ammonia Stored on Degreened Catalysts



Comparison of Improved SCR Catalysts

Ammonia Stored on Aged Catalysts

64h at 670°C



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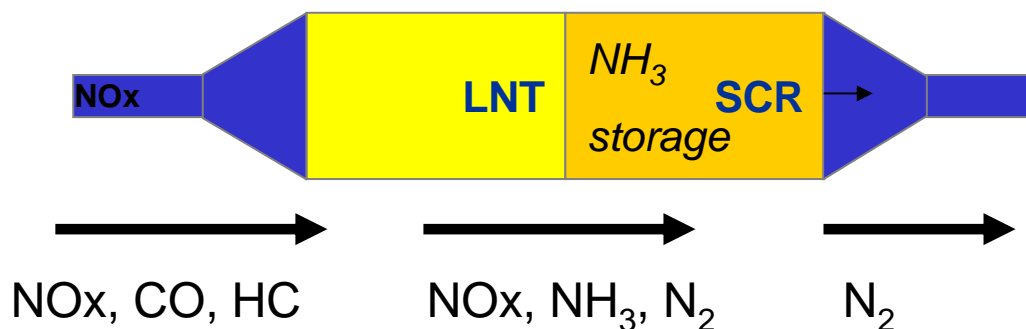
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Comparison of Improved NOx Catalysts

Alternative Ammonia-based Catalyst Systems

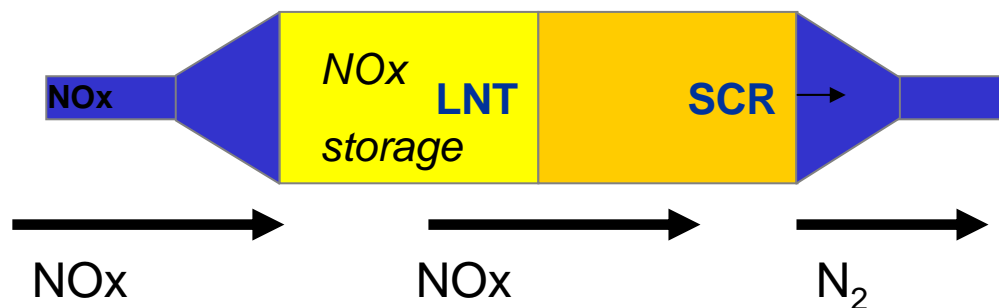
Rich Operation:



Rich:

- NOx stored on LNT is released during rich event and reduced to N_2 and NH_3 .
- Desorbed NOx + NH_3 react over SCR during rich event.
- Excess ammonia is stored on SCR.

Lean Operation:



Lean:

During lean operation NOx slip through LNT is consumed by NH_3 stored on SCR.



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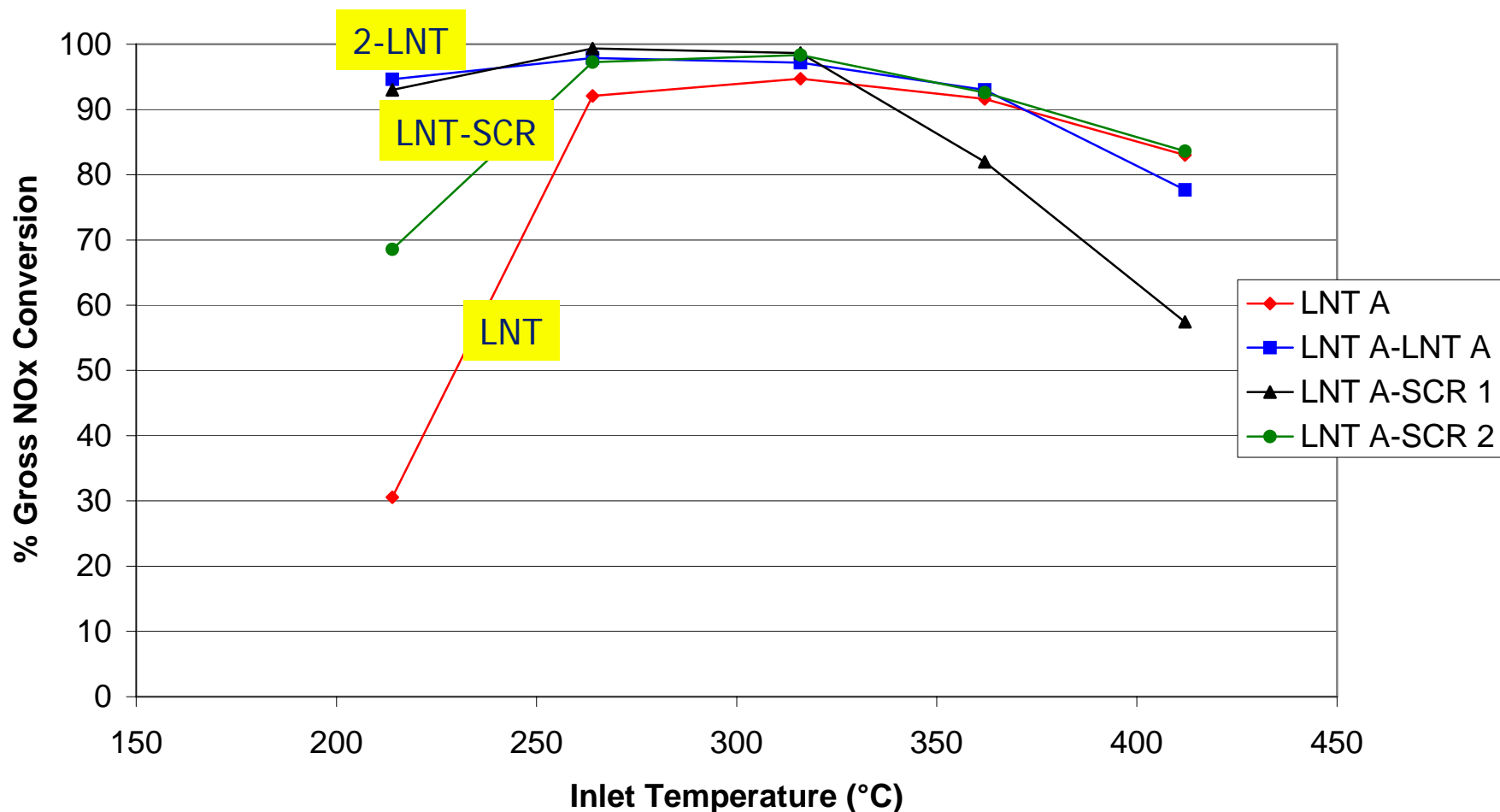
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Comparison of Improved NOx Catalysts

Alternative Ammonia-based Catalyst Systems

Flow reactor, 40s lean, 5s rich, 120K mi aged



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Exhaust Gas Sensor Development



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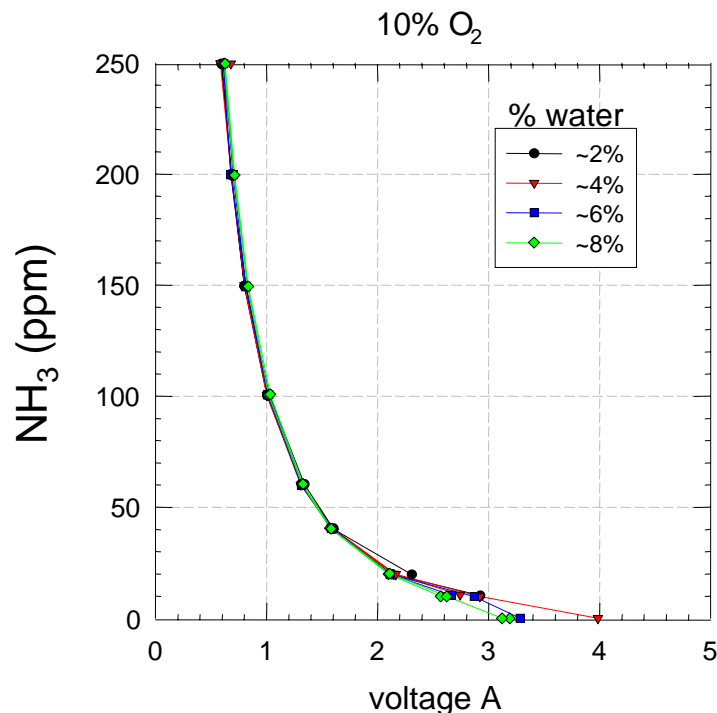
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Exhaust Gas Sensor Development

Prototype NH_3 Sensor Obtained from a Supplier



Little sensitivity to water for $\text{NH}_3 > 50$ ppm.



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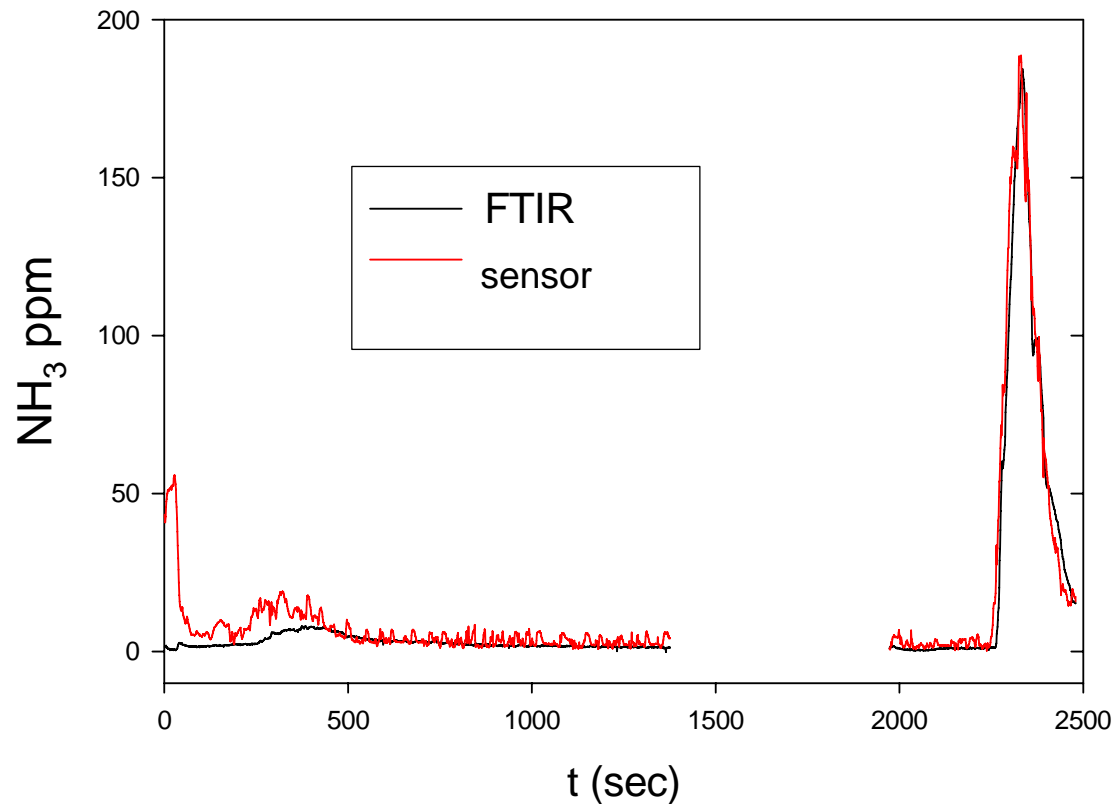
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Exhaust Gas Sensor Development

Vehicle Data with Ammonia Sensor

FTP-75 Emission Cycle



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Urea Infrastructure Study



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Urea Infrastructure Study

Co-fueling Hardware Status

- Co-fueling hardware completed
 - Improved co-axial nozzle with fill-neck insert provided by a major nozzle manufacturer
 - Urea pumping system with flow meter
 - Urea tank integral with dispenser
 - Urea heating system
 - 32.5 wt% urea in water assumed



Urea Infrastructure Study

Co-fueling Hardware Testing

- Tested diesel fuel / urea solution co-fueling using a co-axial nozzle system
- Testing of improved nozzle and insert showed better alignment and improved sealing
 - 1st version: 0.5 vol.% leak rate of urea into diesel
 - 2nd version: < 0.1 vol.% leak rate of urea into diesel
- ***Cross contamination of urea into diesel remains a concern*** for co-axial design due to urea line connection within the diesel re-fueling stream

Conclusions

- The objective of 0.07 g/mi NO_x and 0.01 g/mi PM on the FTP was met with a fresh emission control system of Urea SCR and CDPF.
- HC, CO & PM emissions at 50K mi met Tier 2 Bin 5.
- NO_x emissions at 50K mi were 0.09 g/mi and were predicted to be 0.05 g/mi (Bin 5) if rapid warm-up during cold-start had been available.
- Current DOC AB had highest NO₂ production after aging. New DOC AF had lower HC lightoff T but less NO₂ production.
- New SCR catalysts were developed that have improved NO_x conversion after 120K mi equivalent aging.
- Long-term lean aging at 670°C decreases the ability of base metal/zeolite SCRs to store ammonia.
- SCR catalysts were used downstream of reduced size LNTs with favorable results.
- Prototype NH₃ sensors were successfully tested on a vehicle.
- Cross contamination of urea into diesel remains a concern for co-axial design due to urea line connection within the diesel re-fueling stream

Acknowledgements

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